

US009297659B2

(12) **United States Patent**
Lin

(10) **Patent No.:** **US 9,297,659 B2**
(45) **Date of Patent:** **Mar. 29, 2016**

(54) **COMPOSITE NAVIGATION SYSTEM**

(71) Applicant: **CHUNG HUA UNIVERSITY**, Hsinchu (TW)

(72) Inventor: **Jium Ming Lin**, Hsinchu (TW)

(73) Assignee: **CHUNG HUA UNIVERSITY**, Hsinchu (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 27 days.

(21) Appl. No.: **14/446,069**

(22) Filed: **Jul. 29, 2014**

(65) **Prior Publication Data**

US 2016/0033278 A1 Feb. 4, 2016

(51) **Int. Cl.**
G01C 21/00 (2006.01)
G01C 21/12 (2006.01)

(52) **U.S. Cl.**
CPC **G01C 21/12** (2013.01)

(58) **Field of Classification Search**
CPC G01C 21/28; G01S 19/06; G01S 13/025
USPC 701/468, 472, 532, 470, 476, 479, 480,
701/500, 503, 505, 509; 342/357.52,
342/357.74, 357.42, 104, 118
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,735,523 B1 5/2004 Lin et al.
7,209,221 B2 4/2007 Breed et al.
8,416,186 B2 4/2013 Yamamoto et al.
2005/0143916 A1* 6/2005 Kim G01C 21/28
701/472
2006/0129308 A1* 6/2006 Kates A61H 3/061
701/532
2006/0145463 A1* 7/2006 Isaji B60R 21/0134
280/806

2006/0181400 A1* 8/2006 Cox G06Q 10/087
340/505
2006/0286972 A1* 12/2006 Kates H04M 1/05
455/415
2010/0138115 A1* 6/2010 Kageyama B60R 21/0134
701/46
2010/0141483 A1* 6/2010 Thacher G01S 13/825
340/989
2012/0268308 A1* 10/2012 Tuttle G01S 13/582
342/42
2014/0297171 A1* 10/2014 Minemura G08G 1/166
701/301
2014/0336883 A1* 11/2014 Thompson B60P 1/045
701/50
2015/0234051 A1* 8/2015 Moshfeghi G01S 19/06
342/357.43

FOREIGN PATENT DOCUMENTS

TW 576928 2/2004
TW I372989 9/2012

OTHER PUBLICATIONS

Office Action and Search Report dated Jun. 2, 2015 from the Taiwan counterpart application 103125788.
English abstract translation of the Office Action dated Jun. 2, 2015 from the Taiwan counterpart application 103125788.
English abstract translation of TW 576928.
English abstract translation of TW I372989.
TW576928 is also published as U.S. Pat. No. 6735523 B1.
TWI372989 is also published as U.S. Pat. No. 8416186 B2.

* cited by examiner

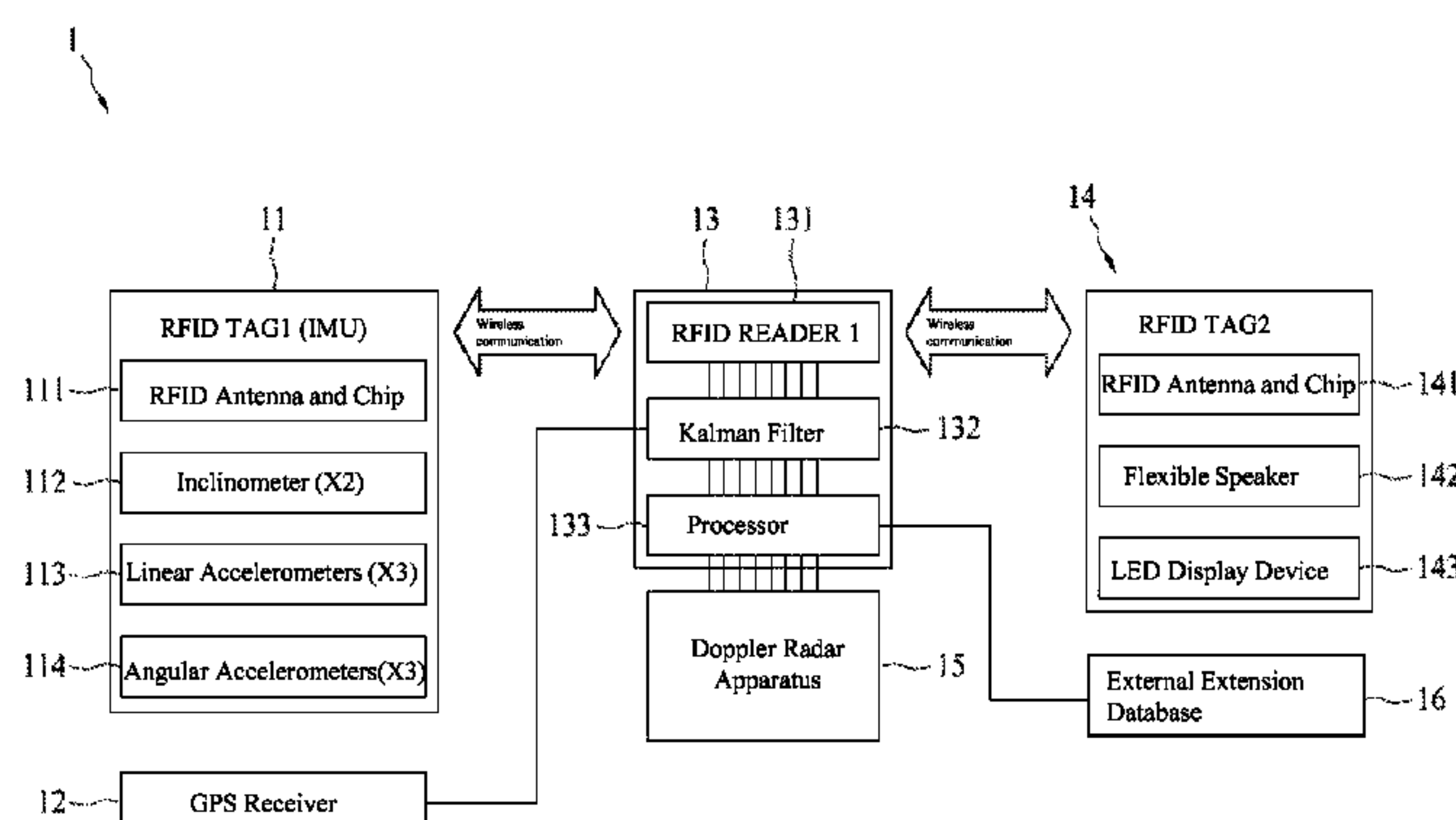
Primary Examiner — Marthe Marc-Coleman

(74) *Attorney, Agent, or Firm* — WPAT, P.C.; Anthony King

(57) **ABSTRACT**

A composite navigation system includes a first RFID apparatus, a GPS receiver, and a signal processing system. The first RFID apparatus includes an RFID chip and an antenna, a plurality of inclinometers, a plurality of linear accelerometers, and a plurality of angular accelerometers. The processing system includes a first RFID reader and a Kalman filter. The first RFID apparatus can communicate with the first RFID reader. The Kalman filter connects to the GPS receiver and the first RFID reader.

17 Claims, 8 Drawing Sheets



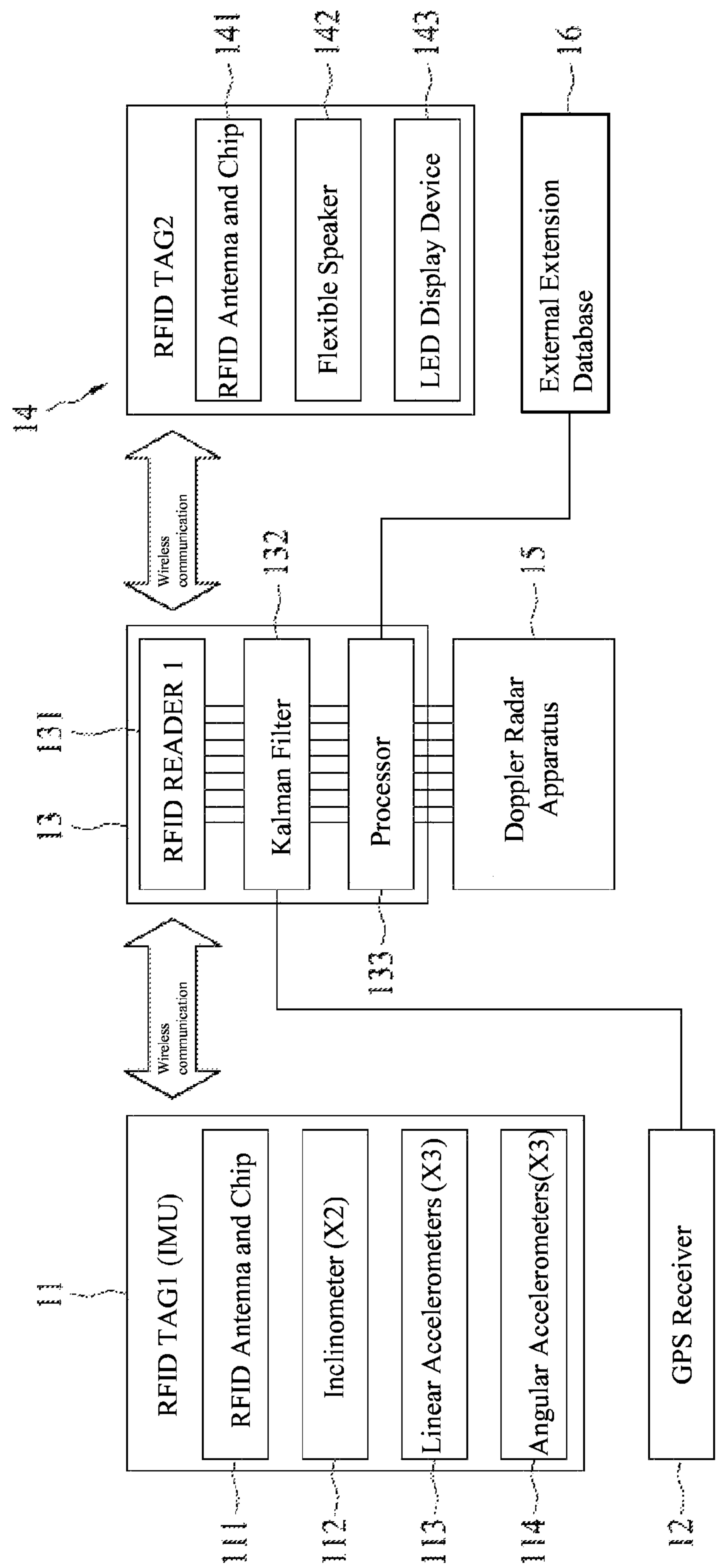


FIG. 1

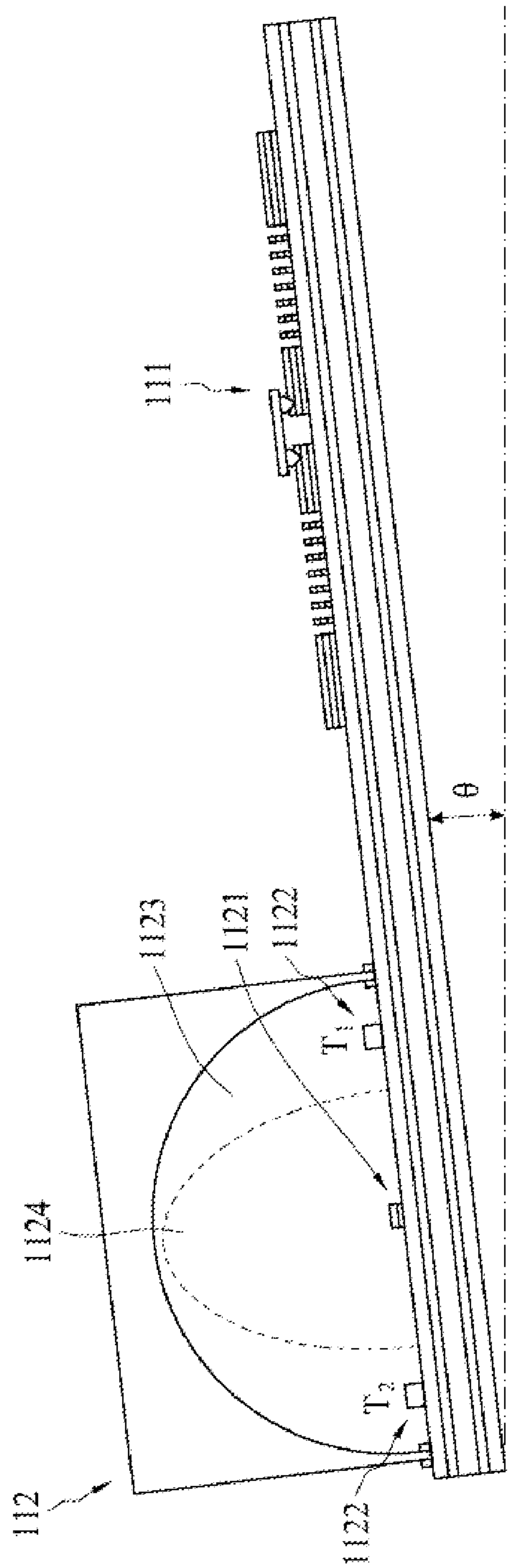


FIG. 2

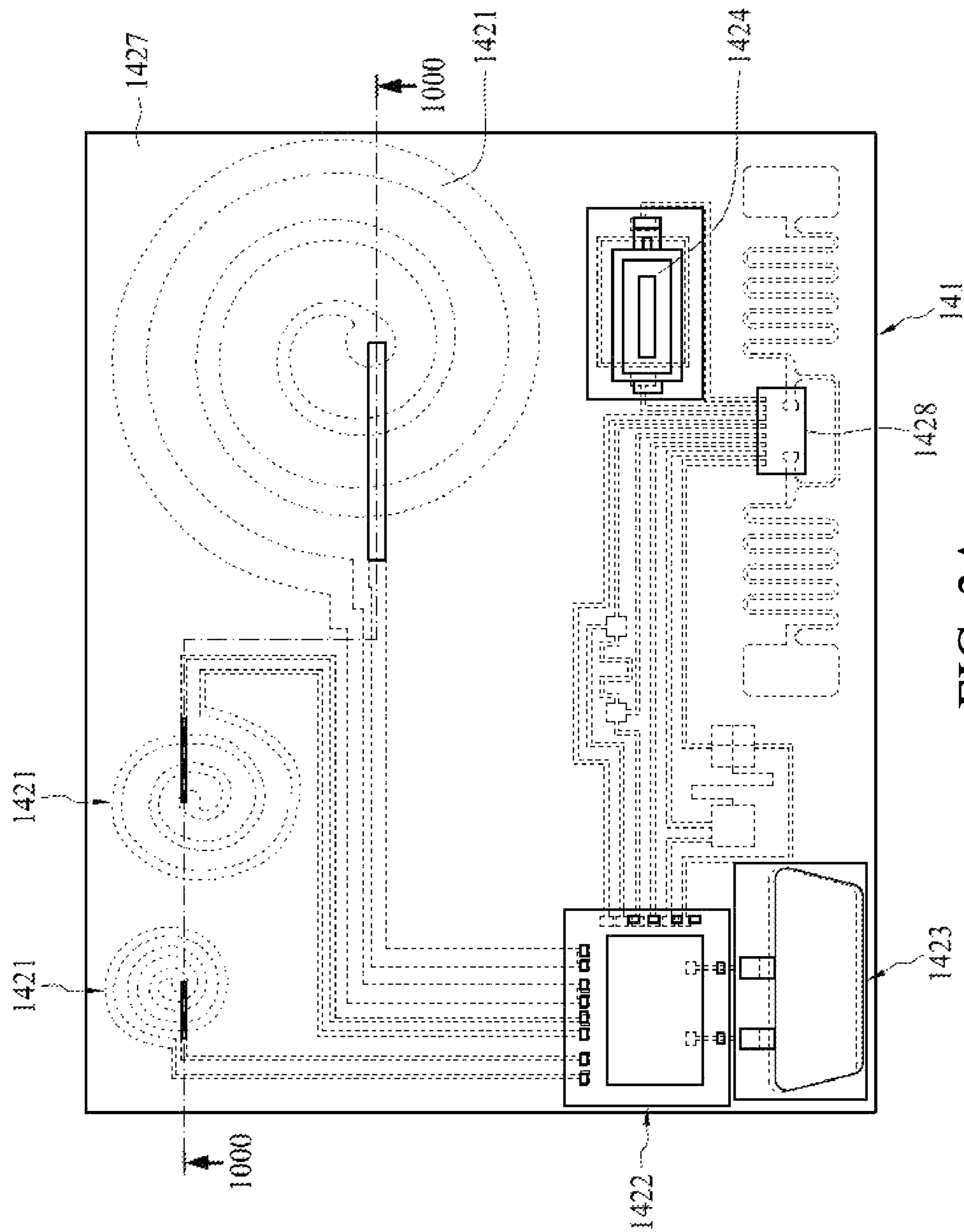


FIG. 3A

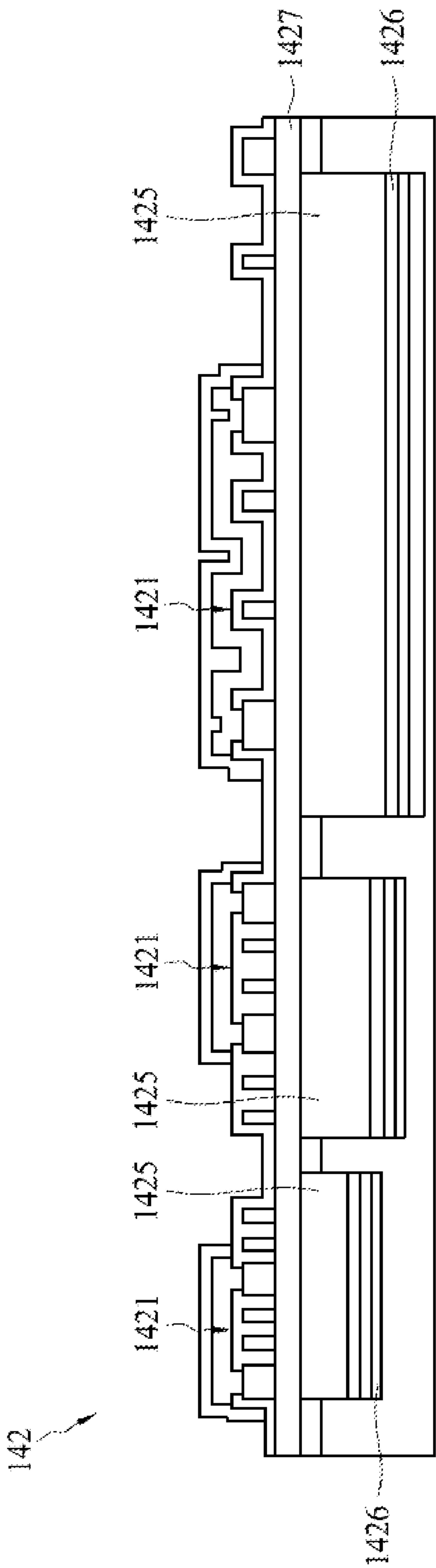


FIG. 3B

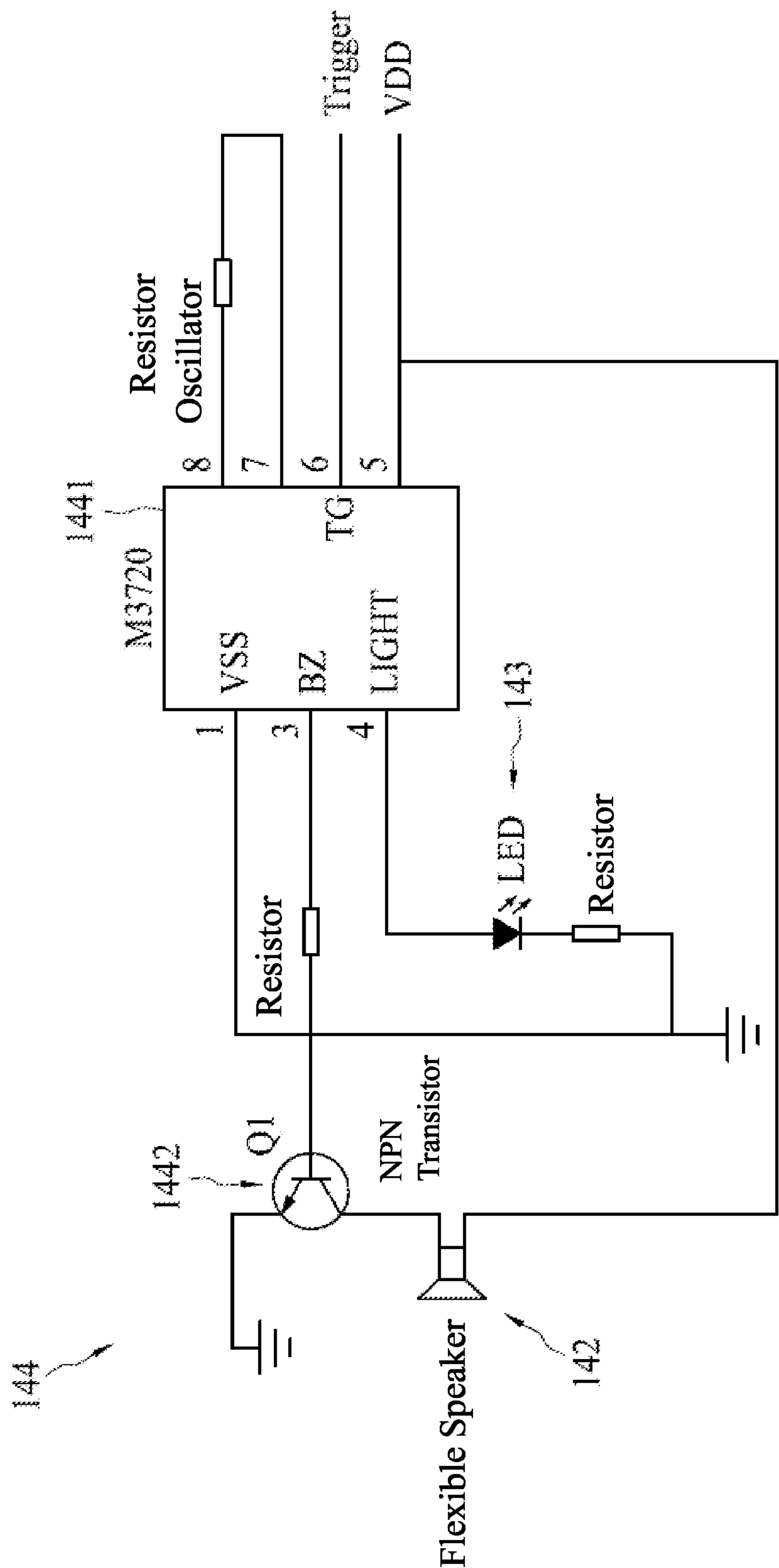


FIG. 4

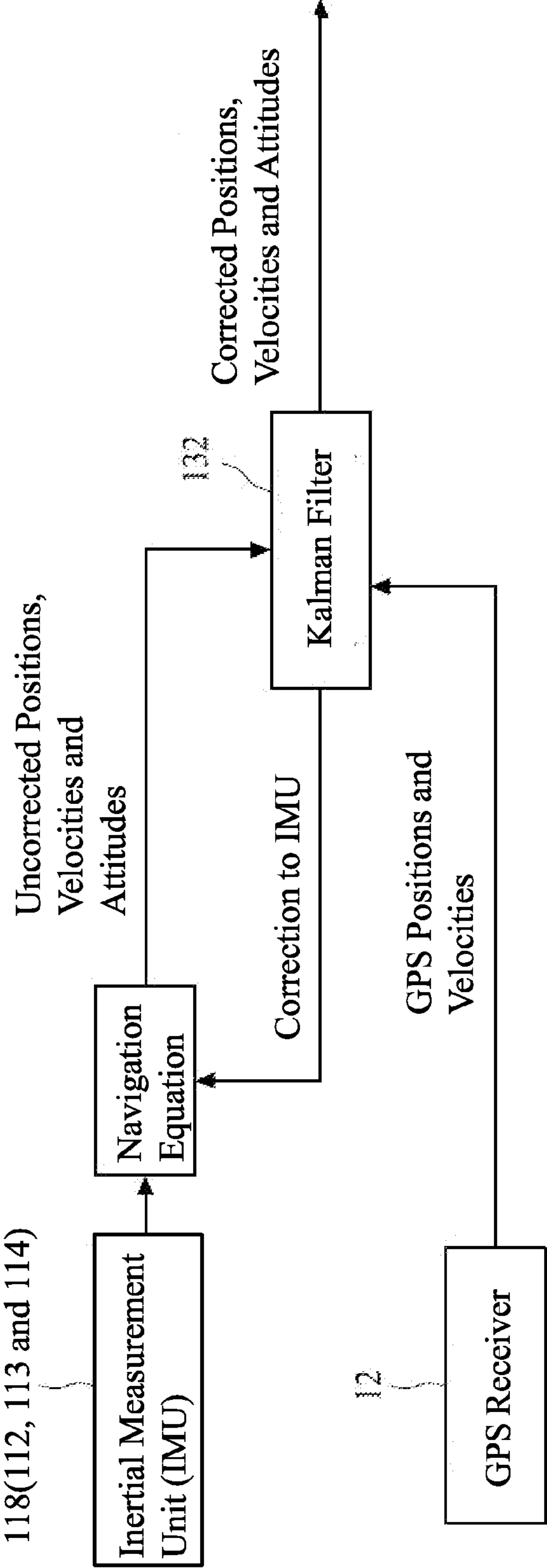


FIG. 5

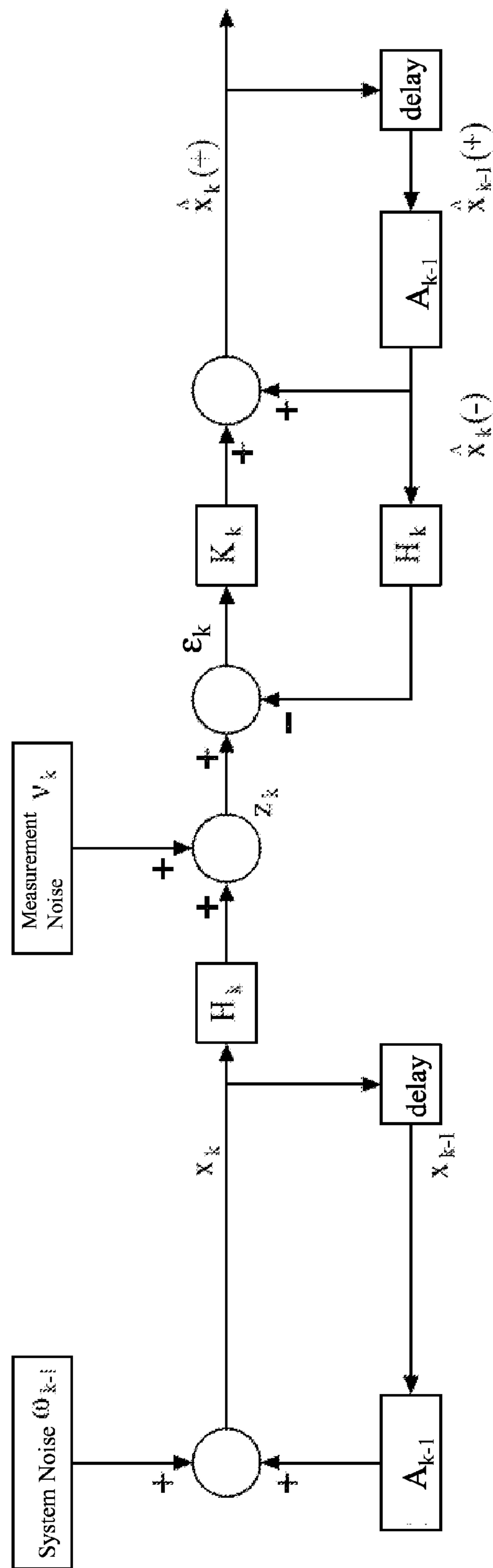


FIG. 6

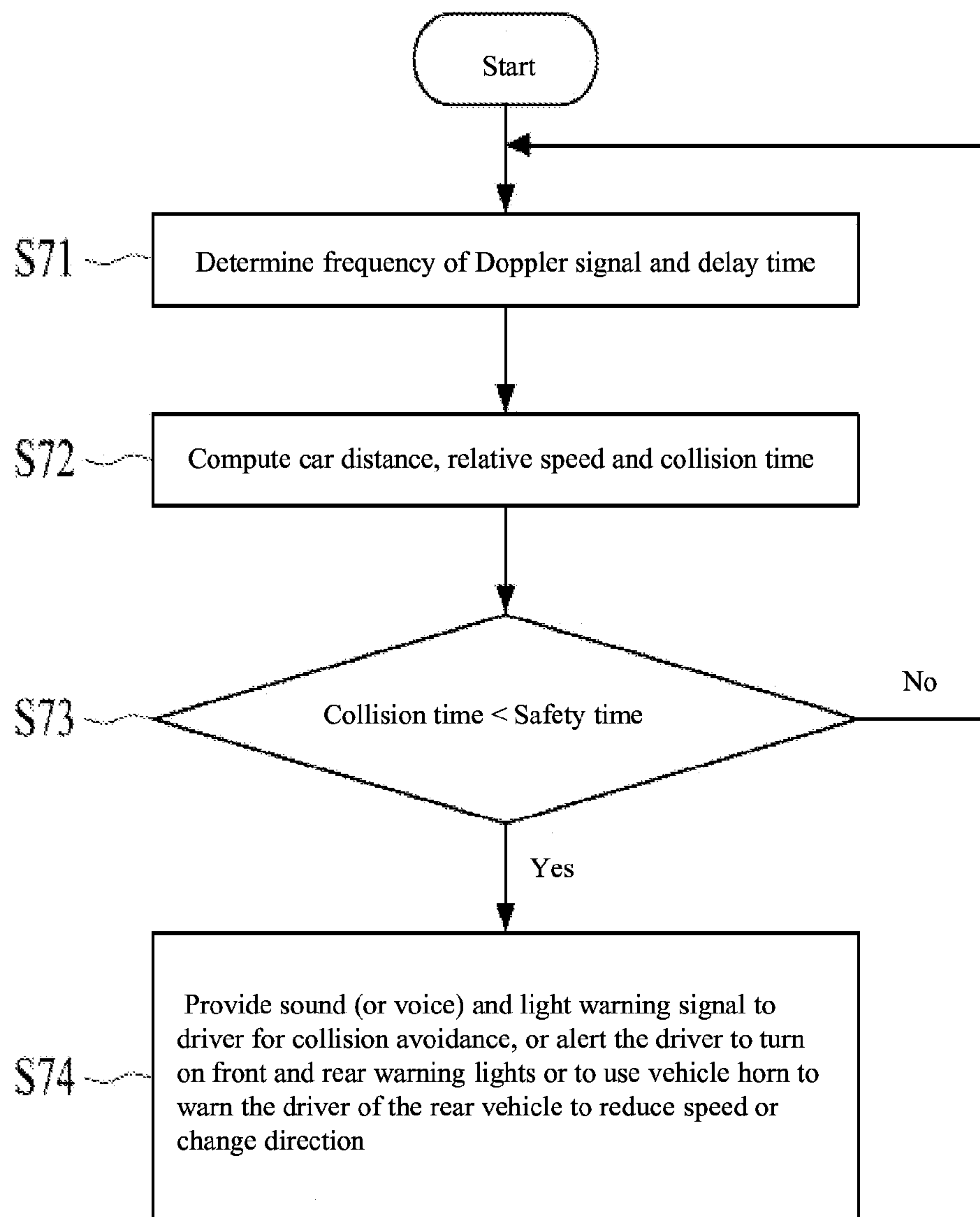


FIG. 7

1

COMPOSITE NAVIGATION SYSTEM

BACKGROUND

1. Technical Field

The present invention relates to a composite navigation system.

2. Related Art

Currently, many automotive electronic appliances, such as GPS devices or event data recorders, are developed to provide assistance to drivers. However, despite the advantages of using such appliances, traffic accidents still frequently occur.

For example, when a combination vehicle attempts to make a turn while accelerating or experiencing side wind currents, the vehicle could excessively tilt and topple over. As a result, an accident will occur, causing harm to passengers and possibly other drivers as well.

In order to reduce the occurrences of serious vehicle accidents, an effective warning and preventive measure are required.

SUMMARY

In one embodiment, a composite navigation system includes a first RFID apparatus, a GPS receiver, and a signal processing system. The first RFID apparatus includes an RFID chip and an antenna, a plurality of inclinometers, a plurality of linear accelerometers, and a plurality of angular accelerometers. The processing system includes a first RFID reader and a Kalman filter. The first RFID apparatus can communicate with the first RFID reader. The Kalman filter connects to the GPS receiver and the first RFID reader.

To better understand the above-described objectives, characteristics and advantages of the present invention, embodiments, with reference to the drawings, are provided for detailed explanations.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described according to the appended drawings in which:

FIG. 1 is a view showing a composite navigation system according to one embodiment of the present invention;

FIG. 2 is a view showing an inclinometer, an RFID chip, and an antenna according to one embodiment of the present invention;

FIG. 3A is a view showing a flexible speaker according to one embodiment of the present invention;

FIG. 3B is a cross-sectional view along line 1000-1000 of FIG. 3A;

FIG. 4 is a view showing a circuit for generating sound or voice according to one embodiment of the present invention;

FIG. 5 is a flow chart showing a method for a Kalman filter according to one embodiment of the present invention;

FIG. 6 is a block diagram related to a Kalman filter according to one embodiment of the present invention; and

FIG. 7 is a flow chart showing a method of determining a collision time of vehicles and generating a warning signal according to one embodiment of the present invention.

DETAILED DESCRIPTION OF DISCLOSED EMBODIMENTS

The following description is presented to enable any person skilled in the art to make and use the disclosed embodiments, and is provided in the context of a particular application and its requirements. Various modifications to the

2

disclosed embodiments will be readily apparent to those skilled in the art, and the general principles defined herein may be applied to other embodiments and applications without departing from the spirit and scope of the disclosed embodiments. Thus, the disclosed embodiments are not limited to the embodiments shown, but are to be accorded the widest scope consistent with the principles and features disclosed herein.

Referring to FIG. 1, in at least one embodiment, a composite navigation system 1 comprises a plurality of first RFID (radio-frequency identification) apparatuses 11, a GPS receiver 12, and a signal processing system 13. The first RFID apparatuses 11 may be disposed on a vehicle or car to detect dynamic information of the vehicle. The first RFID apparatuses 11 is configured to submit detected dynamic information to the signal processing system 13 by a standard RFID communication protocol. The GPS receiver 12 is coupled with the signal processing system 13. The GPS receiver 12 may also be disposed on a vehicle to provide the signal processing system 13 with location information about the vehicle. In some embodiments, the signal processing system 13 is disposed on a vehicle.

Referring to FIG. 1, in some embodiments, the first RFID apparatus 11 comprises an RFID chip and an antenna 111. The signal processing system 13 comprises an RFID reader 131. The first RFID apparatus 11 communicates with the RFID reader 131 of the signal processing system 13 through the RFID chip and the antenna 111. In some embodiments, the RFID chip and the antenna 111 are formed on a substrate included in the first RFID apparatus 11.

Referring to FIGS. 1 and 2, in some embodiments, the first RFID apparatus 11 comprises at least one inclinometer 112. The inclinometer 112 is configured to measure an inclined angle of the vehicle. The first RFID apparatuses 11 can submit the measured inclined angle to the signal processing system 13.

Referring to FIG. 2, in some embodiments, the inclinometer 112 comprises a thermal convection inclinometer. The inclinometer 112 comprises a heater 1121 and two temperature sensors 1122 disposed on two sides of the heater 1121. The heater 1121 and the temperature sensors 1122 are located in a chamber 1123, which can have a hemi-cylindrical or hemi-spherical interior. The chamber 1123 can be filled with gas, such as xenon. Under the influence of the gravity and the filled gas in the chamber 1123, the heater 1121 generates a thermal bubble 1124. The inclined angle of a vehicle can be represented by the equation (1):

$$\Delta T = (T_1 - T_2) = A \times \theta \quad (1)$$

where T_1 and T_2 are temperatures measured by the temperature sensors 1122, and A is a constant.

In some embodiments, the first RFID apparatus 11 comprises two groups of one heater 1121 and two temperature sensors 1122, and the temperature sensors 1122 of the two groups can be connected as a Wheatstone bridge circuit. For further details about the connection, refer to U.S. patent application Ser. No. 13/685,398, the relevant content of which is incorporated herein by reference. In some embodiments, the RFID chip of the first RFID apparatus 11 comprises an amplifier, which is configured to amplify the voltage difference across the midpoints of the Wheatstone bridge circuit and to provide the amplified voltage to an analogue/digital (A/D) converter. A chip that has a part number of nRF9E5 and is manufactured by Nordic Semiconductor is an example of the RFID chip; however, the present invention is not limited to such an example. In some embodiments, a battery 115 is disposed in the first RFID apparatus 11.

3

In some embodiments, the composite navigation system **1** is used in a single vehicle. The composite navigation system **1** or the signal processing system **13** comprises a plurality of inclinometers **112**. The composite navigation system **1** includes a lookup table for a single vehicle. The lookup table shows pitch-roll combinations, yaw turning rates (r), and warning methods and actions, as shown in Table 1. The composite navigation system **1** or the signal processing system **13** is configured to determine a pitch-roll combination ($p=\theta+\Phi$) according to a pitch angle (θ) and a roll angle (Φ), and then, select corresponding warning method and action for a driver according to the pitch-roll combination ($p=\theta+\Phi$) and a yaw turning rate (r) from Table 1.

TABLE 1

Warnings and actions for pitch-roll combination and combined yaw turning rate.				
	$0 < p < 10$	$10 < p < 20$	$20 < p < 25$	$25 < p$
$0^\circ/\text{sec} < r < 5^\circ/\text{sec}$	flashing a white LED light	generating warning sound and flashing a red LED	generating warning sound, flashing a red LED light, and initiating braking or closing the throttle to reduce speed	generating warning sound, flashing a red LED light, and initiating braking or closing the throttle to stop the vehicle
$5^\circ/\text{sec} < r < 10^\circ/\text{sec}$	generating warning sound and flashing a red LED	generating warning sound, flashing a red LED light, and initiating braking or closing the throttle to reduce speed	generating warning sound, flashing a red LED light, and initiating braking or closing the throttle to stop the vehicle	generating warning sound, flashing a red LED light, and initiating braking or closing the throttle to stop the vehicle
$10^\circ/\text{sec} < r$	generating warning sound, flashing a red LED light, and initiating braking or closing the throttle to reduce speed	generating warning sound, flashing a red LED light, and initiating braking or closing the throttle to stop the vehicle	generating warning sound, flashing a red LED light, and initiating braking or closing the throttle to stop the vehicle	generating warning sound, flashing a red LED light, and initiating braking or closing the throttle to stop the vehicle

In some embodiments, the composite navigation system **1** includes a plurality of first RFID apparatuses **11**, which are used in a combination vehicle or a tractor-trailer. The inclinometers **112** of the plurality of first RFID apparatuses **11** respectively measure the yaw turning rates (r_1 and r_2), the pitch angles (θ_1 and θ_2), and roll angles (Φ_1 and Φ_2) of the vehicle units of the combination vehicle, wherein the vehicle units may comprise a tractor unit and a semi-trailer, or two semi-trailers. The composite navigation system **1** or the signal processing system **13** is configured to calculate the sum R ($R=r_1+r_2$) of the yaw turning rates, the sum θ ($\theta=\theta_1+\theta_2$) of the pitch angles, and the sum Φ ($\Phi=\Phi_1+\Phi_2$) of the roll angles. The composite navigation system **1** or the signal processing system **13** is configured to determine a pitch-roll combination ($P=P_1+P_2$; $P_1=\theta_1+\Phi_1$; $P_2=\theta_2+\Phi_2$). The composite navigation system **1** or the signal processing system **13** includes Table 2 as shown below, and the composite navigation system **1** or the signal processing system **13** select corresponding warning and action from Table 2 according to the pitch-roll combination P and the combined yaw turning rate R .

4

TABLE 2

Warnings and actions for pitch-roll combinations and combined yaw turning rates.				
	$0 < P < 10$	$10 < P < 20$	$20 < P < 25$	$25 < P$
$0^\circ/\text{sec} < R < 5^\circ/\text{sec}$	flashing a white LED light	generating warning sound and flashing a red LED	generating warning sound, flashing a red LED light, and initiating braking or closing the throttle to reduce speed	generating warning sound, flashing a red LED light, and initiating braking or closing the throttle to stop the vehicle
$5^\circ/\text{sec} < R < 10^\circ/\text{sec}$	generating warning sound and flashing a red LED	generating warning sound, flashing a red LED light, and initiating braking or closing the throttle to reduce speed	generating warning sound, flashing a red LED light, and initiating braking or closing the throttle to stop the vehicle	generating warning sound, flashing a red LED light, and initiating braking or closing the throttle to stop the vehicle
$10^\circ/\text{sec} < R$	generating warning sound, flashing a red LED light, and initiating braking or closing the throttle to reduce speed	generating warning sound, flashing a red LED light, and initiating braking or closing the throttle to stop the vehicle	generating warning sound, flashing a red LED light, and initiating braking or closing the throttle to stop the vehicle	generating warning sound, flashing a red LED light, and initiating braking or closing the throttle to stop the vehicle

Referring to FIGS. **1**, **3A**, and **3B**, in some embodiments, the composite navigation system **1** may comprise a second RFID apparatus **14**. The second RFID apparatus **14** comprises an RFID chip and an antenna **141**. The second RFID apparatus **14** uses the RFID chip and the antenna **141** to communicate with the signal processing system **13**.

In some embodiments, the second RFID apparatus **14** comprises a flexible speaker **142**. After the second RFID apparatus **14** receives an instruction to issue a warning from the signal processing system **13**, the second RFID apparatus **14** drives the flexible speaker **142** to generate a warning sound. In some embodiments, the flexible speaker **142** comprises a plurality of planar coils **1421** with different sizes. The coils **1421** with different sizes and a plurality of magnetic portions **1426** are used together to vibrate the flexible dielectric substrate **1427** of the flexible speaker **142** such that low-frequency sound, mid-frequency sound, and high-frequency sound is generated. The planar coils **1421** are formed on the flexible dielectric substrate. Below the planar coils **1421** are disposed a plurality of chambers **1425** for resonance of low, mid, and high-frequency sound and the plurality of magnetic portions **1426**. Alternating current is applied to each planar coil **1421**, causing the planar coil **1421** to generate magnetic fields and reverse magnetic fields. The magnetic fields and reverse magnetic fields cause pulling and repelling forces between the coils **1421** and the magnetic portions, resulting in the vibrations of the flexible dielectric substrate **1427**. The vibrations cause air to move back and forth so as to generate sounds. For further details about the flexible speaker, refer to U.S. patent application Ser. No. 13/726,430, the relevant content of which is incorporated herein by reference. In some embodiments, the chambers **1425** and the magnetic portions **1426** are formed on a magnetic alloy plate. In some embodiments, the RFID chip and the antenna **141** are formed on the

5

flexible dielectric substrate **1427** of the flexible speaker **142**. In some embodiments, the flexible speaker **142** comprises an audio amplifier **1422**. The audio amplifier **1422** can amplify an audio signal for the planar coil **1421**. In some embodiments, the flexible speaker **142** comprises an audio socket **1423**. The audio socket **1423** is configured to receive an audio signal. The audio socket **1423** can be coupled with the audio amplifier **1422**. In some embodiments, the second RFID apparatus **14** comprises an RFID chip and an antenna **141**, which can be the chip that has a part number of nRF9E5 and is manufactured by Nordic Semiconductor. In some embodiments, the signal processing system **13** is configured to select different planar coils **1421** to generate different sounds through the RFID chip. In some embodiments, the flexible speaker **142** of the second RFID apparatus **14** may include a battery **1424**.

Referring to FIG. 1, in some embodiments, the second RFID apparatus **14** comprises an LED (light emitting diode) display device **143**. The LED display device **143** comprises a plurality of LEDs with different colors. In some embodiments, The LEDs are disposed on the flexible dielectric substrate **1427** of the flexible speaker **142**. In some embodiments, the composite navigation system **1** or the signal processing system **13** is configured to drive the LED display device **143** to emit white or red light according to Table 1 or 2.

Referring to FIG. 4, the second RFID apparatus **14** comprises a warning circuit **144**. The warning circuit **144** comprises a chip **1441**, which may be the chip with part number M3720; however, the present invention is not limited to such an example. The chip **1441** includes an audio warning program. The chip **1441** can directly, or through an external power transistor, drive the flexible speaker **142** to generate sound. The chip **1441** can be coupled with the LED display device **143** through a light terminal to drive the LEDs to generate light. Moreover, the chip **1441** comprises a trigger terminal to receive a trigger signal and a terminal to connect with a power source V_{DD} .

In some embodiments, the composite navigation system **1** or the signal processing system **13** selects corresponding warning method and action from Table 1 according to a pitch-roll combination p and a yaw turning rate r , and provides a warning instruction for the second RFID apparatus **14** to cause the warning circuit **144** to drive the flexible speaker **142** to generate warning sound or to drive the LED display device **143**.

Referring to FIG. 1, in some embodiments, the first RFID apparatuses **11** comprises a plurality of linear accelerometers **113** and a plurality of angular accelerometers **114**. In some embodiments, the linear accelerometers **113** and the angular accelerometers **114** are used for measuring linear acceleration and angular acceleration of a vehicle, whereby the attitude, positioning, location, yaw turning rate, roll angle, and/or moving speed of the vehicle can be determined as a reference for road safety and navigation. In some embodiments, the plurality of linear accelerometers **113** comprises X, Y, and Z-axis accelerometers. In some embodiments, the linear accelerometer **113** comprises an X, Y, or Z-axis accelerometer of U.S. Pat. No. 8,307,708B2. Each accelerometer comprises two sensing assemblies, and each sensing assembly comprises a heater and two temperature-sensing elements disposed on two sides of the heater. Each sensing assembly is suspended over a corresponding cavity. The temperature sensing elements of the two sensing assemblies are connected as a Wheatstone bridge circuit, the relevant content of U.S. Pat. No. 8,307,708B2 incorporated herein by reference. In some embodiments, the linear accelerometer **113** comprises an X, Y, or Z-axis thermal convection linear accelerometer

6

disclosed in U.S. patent application Ser. No. 13/685,398. The disclosed X, Y, or Z-axis thermal convection linear accelerometer comprises two linear acceleration-sensing devices. Each linear acceleration-sensing device comprises a heater and two temperature-sensing components disposed on two sides of the heater. Each linear acceleration-sensing device is directly formed on an insulating substrate. The temperature-sensing components of the two linear acceleration-sensing devices are connected as a Wheatstone bridge circuit. The relevant content of U.S. patent application Ser. No. 13/685,398 is incorporated herein by reference.

In some embodiments, the angular accelerometer **114** comprises the angular acceleration sensing device disclosed in U.S. patent application Ser. No. 13/932,730. The disclosed angular acceleration sensing device is disposed on an insulating substrate. The angular accelerometer **114** is used for measuring angular acceleration about an axis. The angular acceleration sensing device comprises a sensing group, which includes two temperature-sensing members and a heater disposed between the two temperature-sensing members. The distance between the two ends of the two temperature-sensing members closer to the rotating axis is greater than that between the other two ends distant away from the rotating axis. The relevant content of U.S. patent application Ser. No. 13/932,730 is incorporated herein by reference. In some embodiments, the angular accelerometer **114** comprises the angular accelerometer disclosed in U.S. Pat. No. 8,327,707 B2. The angular accelerometer comprises a flexible substrate, a base layer, at least one cavity, and at least one sensing assembly. The base layer is formed on the flexible substrate. The at least one cavity is formed on the base layer. The at least one sensing assembly is suspended over the at least one cavity. The sensing assembly comprises a heater and two temperature-sensing elements, wherein the two temperature sensing elements are substantially symmetrically disposed on opposite sides of the heater, and the heaters and the two temperature sensing elements extend in a radial direction. The relevant content of U.S. Pat. No. 8,327,707 B2 is incorporated herein by reference.

Referring to FIG. 1, the composite navigation system **1** comprises a GPS receiver **12** and the first RFID apparatus **11** comprises a Kalman filter **132** connected with the GPS receiver **12** and the RFID reader **131**.

Referring to FIG. 5, the composite navigation system **1** of at least one embodiment of the present invention uses a loosely coupled, closed-loop Kalman filter as a navigation system platform. The loosely-coupled, closed-loop Kalman filter uses three single-axis linear accelerometers, three single-axis angular accelerometers, and two thermal convection inclinometers (one for measuring pitch angle and another for measuring roll angle) as a major part of an inertial navigation system (INS) **118**, as shown in FIG. 5. The loosely coupled, closed-loop Kalman filter uses the GPS receiver to determine yaw angle. Because accurate results can be obtained, another inclinometer can be omitted. The INS **118** can be integrated with the GPS receiver **12**. Generally, the GPS receiver **12** can provide stable, non-divergent position data; however, it can only provide one data message per second. Moreover, since the INS **118** generates data fast and the linear accelerometers and the angular accelerometers have drifting and bias issues, the INS **118** has a serious divergent problem. If the output data of the GPS receiver **12** is introduced to the Kalman filter **132**, the divergent problem caused by drifting can be corrected. As a result, integrated GPS receiver **12** and INS **118** can provide accurate position, speed and attitude, and the navigation accuracy and navigation data update speed can be improved.

7

Referring to FIGS. 5 and 6, a continuous or discrete stochastic system and its plant and measurement equations are discussed as follows. In order to simplify explanation, a linear navigation system for a plane is only considered.

Assuming that X_1 is a position on the X axis; X_2 is a position on the Y axis; $X_3=V_x$, where V_x is a velocity along the X axis; $X_4=V_y$, where V_y is a velocity along the Y-axis; $\dot{X}_3=A_x+W_x$, where A_x is an acceleration along the X-axis and W_x represents noise; $\dot{X}_4=A_y+W_y$, where A_y is an acceleration along the Y-axis and W_y represents noise, a navigation equation or state equation for a planar movement can be expressed as:

$$\begin{bmatrix} \dot{X}_1 \\ \dot{X}_2 \\ \dot{X}_3 \\ \dot{X}_4 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \end{bmatrix} + \begin{bmatrix} 00 \\ 00 \\ 10 \\ 01 \end{bmatrix} \begin{bmatrix} A_x \\ A_y \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ W_x \\ W_y \end{bmatrix} \quad (2)$$

Equation (2) can also be expressed by $\dot{X}=Ax+Bu+w$. Equation (2) is solved by using Taylor's series expansion.

$$X_{k+1} = (I + A\tau) \left[X_k + \int_0^\tau (I - A\tau)(B(\tau)\mu(\tau) + w(\tau))d\tau \right] \quad (3)$$

where

$$I = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A\tau = \begin{bmatrix} 0 & 0 & \tau & 0 \\ 0 & 0 & 0 & \tau \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Because the sampling period $T(=\tau)$ is small, equation (3) can be written as:

$$X_{k+1} = \begin{bmatrix} 1 & 0 & T & 0 \\ 0 & 1 & 0 & T \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} X_k + \begin{bmatrix} \frac{T^2}{2} Ax \\ \frac{T^2}{2} Ay \\ 0 \\ 0 \end{bmatrix} \quad (4)$$

Through the above derivations, a state equation as shown below can be obtained.

$$x_k = A_{k-1}x_{k-1} + B_{k-1}u_{k-1} + w_{k-1} \quad (5)$$

The GPS receiver can provide both longitude and latitude data, which can be converted into coordinates (X_1 on the X-axis, X_2 on the Y-axis). The GPS receiver can also provide speed data ($X_3(=V_x)$ is the speed along the X-axis and $X_4(=V_y)$ is the speed along the Y-axis). With the above data, a measurement equation can be obtained

$$z_k = H_k x_k + v_k \quad (6)$$

8

where w_k is system noise and v_k is measurement noise (i.e. the noise of the accelerations A_x and A_y measured by linear accelerometers). w_k and v_k can be viewed as non-correlated white noise. The system noise w_k and the measurement noise v_k can be used to respectively define a covariance matrix of system noise Q_k and a covariance matrix of measurement noise R_k .

$$E[w_k w_k^T] = Q_k \quad i = k \quad (7)$$

$$E[w_k w_i^T] = 0, \quad i \neq k$$

$$E[v_k v_k^T] = R_k \quad i = k \quad (8)$$

$$E[v_k v_i^T] = 0, \quad i \neq k$$

$$E[w_k v_k^T] = 0 \quad (9)$$

Using equation (6) can estimate an optimum state variable of x_k (i.e. \hat{x}_k) at time k , and the precision of the state estimation can be evaluated by a covariance matrix P_k as shown below.

$$P_k = E\{[x_k - \hat{x}_k][x_k - \hat{x}_k]^T\} \quad (10)$$

The Kalman filter **132** can use a state variable $x_k(-)$ before calculation, a known observation quantity z_k , a covariance matrix of system noise Q_k , and a covariance matrix of measurement noise R_k to determine an optimum state variable $\hat{x}_k(+)$ and obtain a minimum P_k . The recursive operation equations (11), (12), (13), (14), and (15) of the Kalman filter **132** are shown as follows:

An error covariance extrapolation equation is represented:

$$P_k(-) = A_{k-1} P_{k-1} A_{k-1}^T + Q_{k-1} \quad (11)$$

A Kalman gain matrix is represented by:

$$K_k = P_k(-) H_k^T [H_k P_k(-) H_k^T + R_k]^{-1} \quad (12)$$

An updated error covariance equation ($P_k(+)$) is represented by:

$$P_k(+) = [I - K_k H_k] P_k(-) \quad (13)$$

Updated optimum estimated states are represented by:

$$\hat{x}_k(+) = \hat{x}_k(-) + K_k [z_k - H_k \hat{x}_k(-)] \quad (14)$$

$$\hat{x}_k(-) = A_k \hat{x}_{k-1}(+) \quad (15)$$

A calculation flow chart of the Kalman filter **132** is as shown in FIG. 6.

An optimum state variable $\hat{x}_k(+)$ can be determined by using the following steps:

Step 1: Define initial system values of $\hat{x}_0(+)$, $P_0(+)$, Q_k , R_k .

Step 2: Use the above equations (11) to (15) to determine an extrapolation value $\hat{x}_k(-)$ before a signal enters the system.

Step 3: Obtain a measurement value z_k from the measurement system.

Step 4: Use the above equations (12) to (14) to determine a gain K_k of the Kalman filter **132**, an updated covariance matrix $P_k(+)$, and an updated state variable $\hat{x}_k(+)$.

Generally, an INS with three linear accelerometers and three angular accelerometers is not expensive. However, the linear accelerometers, the angular accelerometers, and the inclinometers all have drifting and bias issues, and furthermore, long-term use of the INS results in poor precision. In addition, when poor weather conditions occur, GPS signals become weak; or when the geometric dilution of precision (GDOP) of satellite configuration geometry become greater, GPS signals become unreliable. However, if the INS is integrated with a GPS receiver by using a Kalman filter, then the weak points of GPS and INS signal issues can be fixed.

Through equation (12), it can be known that when a GPS signal becomes weak or when the geometric dilution of precision of satellite configuration geometry become greater, the measurement noise R_k of the covariance matrix become large and the gain K_k of the Kalman filter **132** become small; and thus, equation (14) can be further simplified as:

$$\hat{x}_k(+)=\hat{x}_k(-) \quad (16)$$

When GPS signals become weak, the composite navigation system **1** uses three linear accelerometers and three angular accelerometers to produce measurement data. In some embodiments, the GDOP is too large, for example, greater than 15 or 20, which is not a limitation to the present invention. The composite navigation system **1** stops using GPS signals.

When GPS signals are strong or the GDOP is small (or in a range of from 6 to 10), the Kalman gain matrix is equal to an identity matrix, and the composite navigation system **1** will produce a similar result as the GPS receiver. It can be seen that the composite navigation system **1** can produce more precise output in comparison with either an inertial measurement unit (IMU) or a GPS device. Therefore, IMU and GPS devices are ideal complementary navigation structures. Moreover, the composite navigation system **1** comprises a plurality of inclinometers, which can be used for measuring pitch angles and roll angles and integrated with the above-mentioned IMU and GPS devices to correct the drifting and bias issues of the linear accelerometers and the angular accelerometers so that the navigation accuracies of vehicle positions, speeds, and attitudes of INS can be improved and the positioning data update rate can be faster than that of GPS.

Referring to FIGS. **1** and **7**, in some embodiments, the composite navigation system **1** comprises a Doppler radar apparatus **15**. The Doppler radar apparatus **15** is used for measuring a distance and a relative speed between two vehicles. The Doppler radar apparatus **15** is coupled with the signal processing system **13**. In some embodiments, the signal processing system **13** comprises a processor **133**. The Doppler radar apparatus **15** is coupled with the processor **133**.

The antenna of the Doppler radar apparatus **15** emits a strong electromagnetic wave, which hits a rear vehicle and then reflects back. In Step **S72**, the Doppler radar apparatus **15** determines the frequency (F_D) of the reflected wave, and thereby calculates the relative velocities (V_R) of the two vehicles according to the below equation.

$$V_R=C/F_D \quad (17),$$

where C is the light speed.

In Step **S71**, the Doppler radar apparatus **15** of the composite navigation system **1** can determine the frequency of a Doppler signal from a rear vehicle. After the processor **133**

calculates a time delay τ_D , the processor **133** determines a relative distance to a rear vehicle according to the following equation.

$$R=\tau_D V_R/2 \quad (18)$$

In Step **S72**, the composite navigation system **1** or the signal processing system **13** can determine a collision time τ_I by using the relative distance and relative velocity. In Steps **S73** and **S74**, the composite navigation system **1** or the signal processing system **13** generates sound (or voice) through the flexible speaker **142** and a light signal through the LED display device **143** as a reference for a driver if the collision time is less than a predetermined safety time, for example, 5 seconds, which is not a limitation to the present invention. The driver may use a vehicle warning light or a vehicle horn to warn the driver of the rear vehicle to reduce vehicle speed or change direction. The collision time τ_I can be determined by the following equation.

$$\tau_I=R/V_R \quad (19)$$

In some embodiments, the composite navigation system **1** comprises an external extension database **16** coupled with the processor **133**. Referring to FIG. **1**, in at least one embodiment, the signal processing system **13** of the composite navigation system **1** receives data from the GPS receiver and the first RFID apparatuses **11** and sends the data to the Kalman filter for navigation use. The Doppler radar apparatus **15** is used in particular for detecting a relative distance and a relative speed between two vehicles. The processor **13** calculates a collision time and generates sound (or voice) through the flexible speaker **142** and a light signal through the LEDs display device **143** as a reference for a driver if the collision time is less than a predetermined safety time (T_S), whereby the driver may use a vehicle warning light or a vehicle horn to warn the driver of the rear vehicle to reduce vehicle speed or change direction. Regardless of whether an accident occurs, the relevant data including data from the GPS receiver and the first RFID apparatuses **11** and corresponding computed results would be stored in the database **16** for further interpretation and investigation.

It will be apparent to those skilled in the art that various modifications and variations can be made to the disclosed embodiments. It is intended that the specification and examples be considered as exemplary only, with a true scope of the disclosure being indicated by the following claims and their equivalent.

What is claimed is:

1. A composite navigation system comprising:

a first RFID apparatus disposed on a vehicle, the first RFID apparatus comprising a plurality of inclinometers, a plurality of linear accelerometers, and a plurality of angular accelerometers to detect dynamic information of the vehicle;

a GPS receiver; and

a signal processing system comprising:

a first RFID reader configured to communicate with the first RFID apparatus; and

a Kalman filter connecting to the GPS receiver and the first RFID reader,

wherein the first RFID apparatus is configured to submit detected dynamic information to the signal processing system by a standard RFID communication protocol.

2. The composite navigation system of claim 1, further comprising a processor connecting to the Kalman filter.

3. The composite navigation system of claim 2, further comprising an external extension database configured to store data from the first RFID apparatus and the GPS receiver.

11

4. The composite navigation system of claim 2, wherein the Kalman filter uses data from the GPS receiver to correct navigation data from the first RFID apparatus.

5. The composite navigation system of claim 2, wherein data from the first RFID apparatus comprises pitch angle data and roll angle data.

6. The composite navigation system of claim 2, configured to stop using signals from the GPS receiver when geometric dilution of precision of satellite configuration geometry is greater than 15.

7. The composite navigation system of claim 1, further comprising a second RFID apparatus including a flexible speaker.

8. The composite navigation system of claim 7, wherein the second RFID apparatus further comprises a light-emitting diode display device.

9. The composite navigation system of claim 1, further comprising a Doppler radar apparatus, wherein the composite navigation system is configured to determine a relative speed and a distance between cars according to a frequency of a Doppler radar signal from a rear vehicle and a delay time of a reflected Doppler radar signal.

10. The composite navigation system of claim 9, configured to determine a collision time when a collision occurs according to the relative speed and the distance.

11. The composite navigation system of claim 10, configured to compare the collision time with a safety time, and to

12

generate a sound or voice through a flexible speaker and a light signal through a light-emitting diode display device so as to warn a driver.

12. The composite navigation system of claim 1, wherein the first RFID apparatus is configured to measure a pitch angle of a car.

13. The composite navigation system of claim 12, wherein the first RFID apparatus is configured to measure a roll angle of a car.

14. The composite navigation system of claim 13, wherein the signal processing system is configured to determine a sum of the pitch angle and the roll angle.

15. The composite navigation system of claim 14, wherein the signal processing system is configured to determine a method of early warning.

16. The composite navigation system of claim 13, wherein the plurality of inclinometers are configured to determine the roll and pitch angles.

17. The composite navigation system of claim 16, wherein the plurality of inclinometers are used on a combination vehicle and the signal processing system is configured to determine a sum of a plurality of pitch angles of the combination vehicle or a sum of a plurality of roll angles of the combination vehicle.

* * * * *